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Design and construction of a scanning stand for the PU mini-acoustic sensor

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Abstract: The main objective of this work was to design and construct a device that would facilitate and reduce the intensity of work in the process of scanning surfaces with a Microflown PU Mini acoustic probe. Our proposed device will shorten the total time to scan the surface and improve the quality of data measurements. The device was designed to be able to perform movement along the X and Y axes, thus achieving scanning of the entire sound field. Some components of the device are manufactured strictly according to particular specifications to suit our requirements. The most important step in the design of the scanning device we prepared for the particular acoustic sensor was the design for the linear connection that fulfills a supporting function for the entire device as well as provides movement along the X and Y axes. The final step was the design for the automation of the entire system, for which we selected an Arduino Uno (ATmega328) controller. The actual device was tested in the final stages. The device is designed and tested as functional and able to work on what was intended for and is ready for further modifications or use in practice.

Keywords: localize, scanning device, sound intensity, sound sources, visualize

1 Introduction

Modern acoustics is vastly different from the field that existed as recently as 30 years ago. It has grown to encompass the realm of ultrasonics and infrasonics. Improvements are still being made in the older domains of voice reproduction, audiometry, psychoacoustics, speech analysis, and environmental noise control [1]. Acoustics is defined by ANSI/ASA S1.1-2013 as “(a) Science of sound, including its production, transmission, and effects, including biological and psychological effects. (b) Those qualities of a room that, together, determine its character with respect to auditory effects.” ANSI S1.1 was first published in 1960 and has its roots in a 1942 standard published by the American Standards Association, the predecessor of ANSI. The study of acoustics revolves around the generation, propagation, and reception of mechanical waves and vibrations.

1.1 History of acoustics

The historical progress of the science of acoustics is surveyed from the earliest recorded phenomena and theories to the present status of the subject [2]. With the sound as a major factor-affecting human life, it was only natural for interest in the science of sound, or acoustics, to emerge.

The honor of being the earliest acousticians probably belongs to the Greek philosopher Chrysippus (ca. 240 BC), the Roman architect-engineer Vitruvius (ca. 25 BC), and the Roman philosopher Severinus Boethius (480–524). Marin Mersenne (1588–1648), a French natural philosopher and Franciscan friar, may be considered to be the “father of acoustics.” The “father of modern acoustics,” Robert Bruce Lindsay (1900–1985), developed the “Wheel of Acoustics” to illustrate the many fields of study included in the topic of acoustics [3]. Joseph Sauveur (1653–1713) should also be mentioned here, who suggested the term acoustics (from the Greek word for sound) for the science of sound. Ernst F. F. Chladni (1756–1827), author of the highly acclaimed work *Die Akustik* is often credited with

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establishing the field of modern experimental acoustics through his discovery of torsional vibrations and measurements of the velocity of sound with the aid of vibrating rods and resonating pipes.

Acoustics also engendered the science of psychoacoustics. Harvey Fletcher (1884–1990), who is regarded as “the father of psychoacoustics,” led the Bell Telephone Laboratories in describing and quantifying the concepts of loudness and masking (1920–1940). The outbreak of World War II served to greatly intensify acoustics research at major laboratories in Western Europe and in the United States of America. This research not only took on great proportions but has also continued unabated to this day [4,5]. Acoustics is no longer an esoteric domain of interest to a few specialists in the telephone and broadcasting industries, the military, and university research centers. Legislation and subsequent action have been demanded internationally to provide quiet housing, safe, and comfortable work environments in the factory and the office, quieter airports, and streets, and protection in general from excessive exposure to noisy appliances and equipment [6].

1.2 Perspectives of visualization techniques

Sound visualization techniques have played a key role in the development of acoustics throughout history. Many alternative methods and apparatus have been proposed over time [7]. Nevertheless, the current measurement procedures for characterizing sound fields can be classified into three major categories, regardless of the postprocessing techniques applied: step-by-step, simultaneous, and scanning measurements. Each of these techniques can be evaluated simply using three main features: measurement time, flexibility, and total cost of the equipment [5,8,9].

Chladni introduced one of the first methods focused upon the visualization of sound and vibration phenomena at the end of the eighteenth century [10]. The method was based on using sand sprinkled on vibrating plates to show the dynamic behavior of a vibrating body. He generated the so-called Chladni patterns by strewing sand on a vibrating plate excited with a violin bow causing the sand to collect along the nodal lines. The first scanning technique for displaying sound was presented by Kock and Buchta in 1965 [11]. He worked extensively on improving his apparatus, which led him to later publish the book *Seeing Sound*. In addition, he also developed a subtraction technique for visualizing wave patterns across a sound field. During the 1970s, multichannel microphone arrays were first applied for sound source localization, although

the idea of developing such a device was first proposed during World War I. Billingsley invented the microphone antenna or so-called “acoustic telescope,” in 1974 [12]. Since 1999, this group of apparatus has been cataloged as “acoustic camera” [13]. As has been mentioned above, there is notable interest in developing tools to assess the behavior of sound in both qualitative and quantitative terms. Generally, in acoustics, it is often necessary to describe not only the characteristics of the location and nature of the sound sources but also the behavior of the sound field that they generate. Consequently, the introduction of a measurement technique, which permits the acquisition of such information in an efficient way without raising the cost or complexity of the measurement setup, has a high potential for a wide range of applications [5,14–16].

1.3 The Microflown PU mini (Scan&Paint)

The Microflown device; see, e.g., ref. [17] is the only one based on the technology of a MEMS (microelectromechanical systems) acoustic sensor that measures the particle velocity instead of the sound pressure, as conventional microphones usually do, providing a new approach for measuring sound intensity. Due to the heating of two microscopic wires placed in parallel, this sensor can quantify the velocity of air particles, which, combined with a pressure microphone, enables us to describe the sound field completely.

There is a sound visualization technique proposed as an alternative sound visualization method called “Scan&Paint” [18]. The acoustic signals of the sound field are acquired by manually moving a single transducer across a measurement plane while filming the event with a webcam. With this probe, it is possible to measure quantities like sound intensity (see, e.g., ref. [19]), sound energy (see, e.g., ref. [20]), and acoustic impedance (see, e.g., ref. [21]) in one direction. In many cases, PU probes have a low susceptibility to background noise and can be used in the entire audible frequency range. Both the sound pressure and the acoustic particle velocity are measured simultaneously [1]. There are different methods to capture and visualize acoustic properties near an object. With PU probes, the velocity from the surface is directly and easily measured.

2 Material and methods

The basis for the structure of the SSAS (scanning stand for the PU Mini acoustic sensor) was chipboard 20 mm

thick, to which were fastened all designed components of the device. Components (bearing platform upper 2 pcs, lower 3 pcs; horizontal rod holder 5 pcs, see Figure 1; servo motor mounting platform 2 pcs), which were designed in a specific size and shape and were made through 3D printing, enabling the reduction of the overall cost of producing the device.

The components were printed using a PRUSA i3 MK3 3D printer and created in Solid Edge 2020. PLA filament 1.75 mm was used for printing, which is one of the most versatile materials for FDM printing technology. PLA is a fully biodegradable material, from corn or potato starch or from sugar cane. It is increasingly used industrially. The time required to print all components was 19 h.53 min. The amount of filament used was 73.58 m, used print quality was 0.20 mm quality. The approximate price of the print was set at 5.48 € [22].

For the supporting function of the moving parts, we chose unsupported polished rods for their lightweight acting on the linear connection. We fixed them to the base plate using horizontal brackets. The linear bearings played an important role in ensuring linear motion. These perform the movement in the *X* and *Y* axes by moving around the sliding surface of the rod with minimal friction. For these bearings, we designed housing to facilitate attaching the upper part of the device to the lower linear connections and which also serves as a housing for the PU Mini sensor (1 pcs). Movement along the *X* and *Y* axes is provided by two NEMA SX17-1003LQCEF two-phase stepper motors with a 4-ply cable of 70 cm. The engines are fastened to the baseboard with screws on the auxiliary fitting. The motor shaft (5 mm) is a flexible coupling connected to a driven shaft (10 mm).

Arduino Uno R3 is a development board with an AVR ATmega328 microcontroller. The board includes 14 digital and 6 analog I/O connectors for connecting an external power supply, a reset button, and a status LED. Other

optional peripherals must be connected separately. The advantage of this device is that it is easy to connect and program. Custom programming is performed in a simple environment, using the Arduino IDE programming language derived from Wiring. The code is very clear, and it separates the programmer from the complex hardware configuration. Arduino is an “Open Source” platform for the easy design and development of electronic programmable devices.

The density of programmable measuring points can vary depending on the nature and complexity of the scanned sound source. It follows that before scanning it is necessary to make test measurements to determine the feed rate and density measurement points of the sensor. This set up is the basis of the quality of measured outputs in the form of acoustic images, which means even better analysis and interpretation of measurement data.

3 The construction and verification of the scanning acoustics stand

Our proposed SSAS guide frame was made for laboratory research and dimensionally adapted to analyze sound sources from smaller industrial sources or household appliances to a size of 1 m × 1 m. The device was designed to be able to perform movement along the *X* and *Y* axes, thus achieving scanning of the entire sound field. The sequence of steps is shown in Figures 2–5.

Step 1: selection of appropriate materials and finish of the desired size, shape, production of subcomponents via 3D printing, workshop finishing of openings. Step 2: engine modifications, mounting on the platform, attaching to the baseboard of the guide frame. Step 3: (a) mounting components on the base plate (horizontal rod holders, sensors, bearings for nuts, bearings); (b) to avoid accidental damage (curling) of the frame and thus the entire scanning device, the whole baseboard was reinforced by a support frame made from chipboard, adding strength and durability to the whole design; (c) for defining the movement path of the baseboard, there are mountings for the guide and the threaded rod together with the motor. The motion sensor on top of the platform is limited to movement along the *X*-axis, while the lower threaded rod ensures the movement of the entire device along the *Y*-axis; and (d) protecting cabling for the two motors from damage from movement using super-quiet energy chains for limited space (E3 system). Step 4: completing, programming, setup, installing the sensor, start-up, and verification of the device.

Figure 1: The proposed horizontal rod holder.

Figure 2: Step 1 – Component selection and printing.

Figure 3: Step 2 – Modifying and fastening the motors to the SSAS guide frame base plate.

Figure 4: Step 3 – Design procedure SSAS.

Figure 5: Step 4 – Final product SSAS.

The device we have designed has the primary purpose of measuring the acoustic characteristics of the close field. The device has to include a probe that is specifically designed for measuring acoustic characteristics in exactly this kind of field. Microflow technology is focused on measuring acoustic quantities. Based on these assumptions, we chose a Microflow PU Min probe as our scanning device. The sound probe combines two sensors: a traditional microphone and a Microflow. The sound pressure and acoustic particle velocity are measured directly in one place. Two complementary acoustic properties, the scalar value “sound pressure” and the vector value “particle velocity” describe any sound field [17].

The parameters of the Microflow sensor that was used in the measurement are as follows:

Acoustical properties microflow element: frequency range: 0.1 Hz to 10 kHz ± 1 dB; upper sound level: 125 dB; polar pattern (figure of eight); directivity (directive).

Acoustical properties microphone element: frequency range: 20 Hz to 20 kHz ± 1 dB; upper sound level: 110 dB; polar pattern (omnidirectional); directivity (omnidirectional).

The speed of the sensor feed also affects the quality of the output data from the measurements. We found the optimal movement for scanning using a number of measurements. By verification, it was found that more accurate measurement values are obtained at low movement rates than at higher ones. Therefore, before the actual measurement, it is advisable to know the actual source of the sound (character of the sound), for subsequent optimal adjustment of scanning parameters (movement speed, point resolution, etc.). Regulation of the angular speed of the electric motor, on which the feed speed of the sensor depends can be regulated by the command in the Arduino IDE program; see Figure 6 [23]. The optimal feed rate of the sensor is from 10 to 30 mm/s. At higher feed speeds, inaccuracies in audio and video synchronization occur during subsequent data processing. After trying motors programmed for this purpose, we found that the device is capable of performing the function for which it was designed. Testing separately, we move the deposit sensor to the X-axis and move the upper part of the assembly equipment along the Y-axis. Then, we can test the entire device in laboratory conditions.

In the frequency range 315–630 Hz, measurement without a rear cover shows that noise is generated by the direct-drive motor area; the same effect is not visible in the frequency range 1,000–2,000 Hz (see Figure 7). These outcomes were compared with the results from the other two acoustic cameras from Gfai Tech GmbH

Figure 6: Created code for controlling the system.

Figure 7: Acoustic picture of frequency range from 315 to 630 Hz (left) and 1,000–2,000 Hz (right).

and Noise Inspector. From comparative outputs, it can be concluded that the proposed device for the presented PU Mini sensor is suitable for use in laboratories and industrial operations where a short time is needed to locate the cause of the faults and adverse states of machinery and equipment using sound parameters.

4 Discussion and conclusion

The modern way of life has also brought the problem of noise and its impact on both human health and the quality of life in general. There are many unwanted sources of noise in our industrialized society. Localizing them is challenging. At present, there are several standard techniques. However, there is no universal solution. The Scan&Paint method makes it possible to localize stationary sources, within a few minutes under operating conditions. A simple scan of the surface is recorded by a video camera and synchronized with the audio data. The position of the probe can be recognized by the video and the color map can be calculated in very high resolution. The usage of the Microflown PU probe in combination with the Scan&Paint software tool enables additional information to be captured compared to the traditional methodology, such as the spatial distribution over the sample visualized through color maps, for detecting weak points, leakages, or assembly defects.

Comesaña and Wind [24], in 2011, at the SAE International conference published a paper, which presented the two main algorithms: the point method and the grid method. The results prove a strong agreement between the two methods. It was found that the point method

provided higher spatial resolution color maps, whereas the grid method converges to a more accurate answer, mainly due to the spatial averaging applied. The scanning device presented in this article is based on the findings of Comesaña, which means that we designed it using the point method algorithm.

The main aim was to simplify, clarify, and streamline the scanning process for the measurement of sound recording and calculating acoustic images, which are relevant data for subsequent analysis and diagnosis of faults and adverse states of the studied machinery and equipment [25,26].

The main advantages of the designed scanning device particularly include the ability to improve the accuracy of the measured data as making a sound recording is limited by the human factor. A device engineered this way can be used for stationary sound sources such as smaller industrial sources or household appliances. The completed apparatus is not limited in terms of size in the case of major industrial sources of sound. Based on customer needs, the presented equipment can be dimensionally adjusted in terms of the size of the scanning area. The production costs of the scanning system do not exceed the sum of 300 €. These costs, however, do not include the Microflown measurement system. We assume that from the construction point of view, it will be possible to apply the proposed stand also when scanning devices generating electromagnetic fields using E- and B-field sensors.

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